8. Conclusions and Recommendations

We conclude that high capacity RF communications from large distances is achievable. Section 8.1 summarizes the conclusions of this report, and the recommendations are found in section 8.2.

8.1 Conclusions

This report considers methods to increase the capacity of an RF system to achieve very high data rates at Mars distances. The thesis of this report is that significantly higher downlink data rates are achievable by utilizing new RF technology. The technology enables much higher EIRP with small increases in spacecraft mass and reasonable increases in the Earth station effective aperture requirements. The uplink, not considered in this study, is easily enabled because it almost always carries lower data rate traffic than the downlink.

There are three major objectives of this report:

1. Demonstrate that 1 Gbps return data rates in 2020 operational systems are possible using technology that is ready, or nearly ready, to fly today.
2. Describe conceptual designs of spacecraft telecommunications transmit subsystems for data rates 1 Gbps and 500 and 100 Mbps for a Mars telecom orbiter at maximum Earth-Mars distance.
3. Recommend strategic investment in technologies that offer design options for RF communications to meet high-data-rate needs.

These three objectives were met:

The conclusion is that 1-Gbps data rates are achievable from Mars distance by (1) increasing the spacecraft RF power transmitted and size of the spacecraft antenna; (2) using power-efficient, high-order modulation and near-capacity coding, and (3) using larger ground aperture from the Earth-based array. The study also indicates that required technology will be ready well before 2015 and can enable an operational architecture by 2020. The study further indicates that the needed power systems are ready today, but have yet to be flown.

8.2 Recommendations

Earth sciences today collectively transmit data hundreds of Mbps to Earth. The DSN presently supports deep space science by receiving data in the 10 to 100 kbps range. The DSN has historically increased its capability in step with a steady increase in the quantity of data available from deep space. With the advent of a renewed exploration age and the desire to maximize scientific value by maximizing the amount of data that can be returned to Earth, it is with high probability that orders of magnitude more data will be available in deep space by 2030 and will some day be returned to Earth at transmission rates that match those now transmitted from near Earth via the Space Network (100s of Mbps).

This report summarizes technologies that enable the realization of tomorrow's communication needs. Technologies that can reduce the mass per bit such that 1 Gbps can be transmitted from the maximum Mars distance using reasonable space and ground resources are identified. Based on the report's findings, the following technology investment strategy is recommended.

1. Investment in lightweight antenna systems that can realize a total antenna mass density of 1 kg/m^2.
2. Investment in a cost-effective, Ka-band receive, 12-m antenna array to upgrade the capability of the DSN. The flexibility of such an array was illustrated by example to show support for a CEV in transit to Mars with at least a 1-Mbps direct-to-Earth capability, and up to a 1-Gbps at Mars maximum-distance via a Mars relay satellite from a CEV in Mars orbit.
3. Realization of coding and modulation technology that can save 3 dB or more over present systems.
4. Efficient generation of RF power up to 1 kW or higher.

Results in chapters 4 and 7 provide guidance on balancing the contributions to the system EIRP from antenna technology and amplifier technology. The study achieved this balance by minimizing EIRP mass, conditioned upon accepting a reasonable level of risk. It was assumed that accepting a reasonable level of risk for each of the two EIRP elements independently lead to the level of EIRP risk that was the greater of the two. Thus, for example, power levels greater than a kilowatt were considered too high a risk to be considered reasonable. The word reasonable is used in the sense that by 2020 the technology could be at least at a TRL 6 level. However, as has been shown there are a number of antenna technologies and RF power technologies that achieve acceptable mass and risk values for a given EIRP value. NASA cannot invest in all of them. Additionally, the notion of risk needs to be assessed on a quantitative and objective basis. This is especially true for technologies such as space application of solid-state Ka-band amplifiers for which insufficient data on system reliability exists.

In addition, the SCAWG frequency plan allocates both Ka-band and X-band for Mars and MARS relay links to/from Earth. Given the large aperture antennas required to support Ka-band data rates, the antenna will realistically be required to be a dual band antenna. In this context complexity may exist in such an implementation when a Ka-band pointing subsystem is required. Thus the concept of minimizing EIRP mass should be extended to a dual band (Ka-band and X-band) system.

It is therefore desirable to take the results of this study to the next level to determine

1. Which paired antenna/power technologies work best together as a function of EIRP?
2. The impact of a dual-band antenna system on various antenna technology options.
3. How the dual-band system impacts the selection of antennas, RF power, and electronics.
4. What are the impacts on the spacecraft?

This will allow NASA to make a more informed decision as to which technologies it should invest in.